

# Highlights of NRL's First 75 Years

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Galactic Radiation Background (GRAB)

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Over-the-Horizon Radar

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Semi-insulating Gallium

Arsenide Crystals

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First U.S. radar, the XAF,  
installed on the USS *New York*

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Global Positioning System

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# SPECIAL HISTORICAL MOMENTS

## NRL Scientists Receive Nobel Prize

NRL has produced two Nobel Laureates, J. Karle and H. Hauptman, who each received the Nobel Prize for Chemistry in 1985 for devising direct methods employing X-ray diffraction analysis in the determination of crystal structures.



X-ray diffraction analysis involves the determination of the arrangement of atoms in crystals from which the molecular formula is derived directly. Determination of the molecular structure is important in that once the structural arrangement is understood, the substance itself can then be synthesized to produce useful products. This research occupies an almost unique position in science because the information it provides is used continuously in other fields. In fact, many phenomena in the physical, chemical, metallurgical, geological and biological sciences are interpretable in terms of the arrangements of atoms.

Methodologies for determining molecular structures are major contributions to science and technology. For example, they form the basis for the computer packages used in pharmaceutical labs and research institutions worldwide for the analysis of more than

10,000 new substances each year. A significant portion of structural research has direct application to public health, including the identification and characterization of potent toxins found in animals and plants, antitoxins, heart drugs, antibiotics, anti-addictive substances, anticarcinogens, and antimalarials.

## Bower Award and Prize for Achievement in Science Awarded to NRL Scientist

In 1993, NRL scientist Dr. Isabella Karle was awarded the Bower Award and Prize for Achievement in Science for her groundbreaking achievements in crystallography and molecular chemistry. In receiving the award, Dr. Karle was cited by the Franklin Institute of Philadelphia for her “pioneering contributions in determining three-dimensional structure of molecules, making use of both X-ray and electron diffraction, and in particular for her definitive introduction ... of the symbolic addition method to reveal molecular structure directly from X-ray studies.”

The Award, presented as a memorial to Dr. Benjamin Franklin, honors outstanding achievement and innovation in the life and physical sciences and its application to service in the public good. Dr. Isabella Karle is the fourth recipient of the prize and the first woman to receive it—clearly a fitting recognition of her half-century career in science and service to NRL, the United States Navy, and mankind in general.



# SPECIAL HISTORICAL MOMENTS

## Robert J. Collier Trophy Awarded to the Global Positioning System Team



On February 10, 1993, the National Aeronautic Association (NAA) selected the Global Positioning System (GPS) Team as winners of the 1992 Robert J. Collier Trophy, the most prestigious aviation award in the United States. This team was composed of researchers from the Naval Research Laboratory, the U.S. Air Force, the Aerospace Corporation, Rockwell International Corporations, and IBM Federal Systems Company. The citation accompanying the presentation of the trophy honors the GPS Team “for the most significant development for safe and efficient navigation and surveillance of air and spacecraft since the introduction of radio navigation 50 years ago.”

The Collier Trophy, established in 1912, is given annually “for the greatest achievement in aeronautics or astronautics in America, for improving the performance, efficiency, or safety of air or space vehicles, the value of which has been thoroughly demonstrated by its actual use during the preceding year.” The original Collier Trophy is on permanent display at the National Air and Space Museum of the Smithsonian Institution.

## SYSTEMS

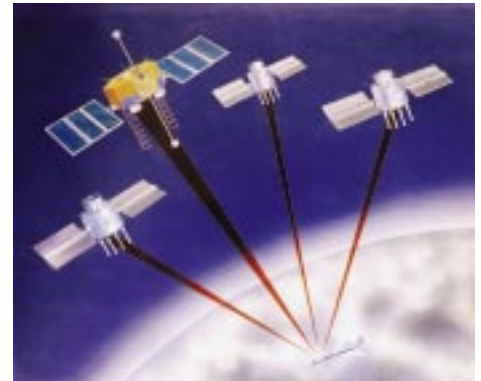
### Global Positioning System

In the 1960s, NRL and the Aerospace Corporation independently developed concepts for systems that could provide precise, all-weather, real-time, 24-hour, worldwide navigation information. The NRL concept was proven in 1967 with the launch of its Timation I satellite. In 1973, NRL’s program merged with the Air Force program to form the Navstar GPS program.

NRL’s Navigation Technology Satellite II, launched in 1977, was the first satellite in the Navstar GPS. The GPS incorporates NRL’s concept of time range, range-rate navigation and a 12-hour orbit. The developmental Block I satellites were an unprecedented success. In more than 700 air, land, and sea tests conducted between 1977 and 1979, they exceeded all performance requirements and affirmed the system’s extraordinary precision.

The Navstar GPS satellites transmit a constant signal generated by on-board atomic clocks, which are so precise that they gain or lose only one second every 3 million years. Users equipped with a receiver/processor simply lock onto the signals of four satellites, and then latitude, longitude, altitude, and velocity are automatically computed—within meters—by triangulation.

This remarkable precision proved invaluable during Operation Desert Storm in targeting pinpoint strikes and positioning troops in featureless terrain. GPS has also been used in Operation Restore Hope to help aircraft land on makeshift Somali airfields. Apart from its primary military function, the satellite system serves numerous peacetime functions such as air traffic control, scientific surveying, harbor navigation, and measurement of ocean waves. Today, a combination of development and production satellites is orbiting the Earth, transmitting continuous navigation signals to users around the world. The system hoped for 30 years ago has become the DoD standard and, in the process, has revolutionized the science of navigation.



# SYSTEMS

## COMMUNICATIONS SYSTEMS

### High Frequency Radio Equipment

NRL's development of radio equipment such as quartz crystal frequency control, high-power transmitters, and receivers led to the adoption and extensive utilization of high frequency (HF) by the Navy and had a profound effect on Naval communications for the next 50-60 years. NRL's HF radio equipment enabled the following achievements:



- The NRL-developed HF transmitter and receiver was carried by the Navy's dirigible USS *Shenandoah* during its transcontinental trip in 1924. This equipment accomplished the unusual feat of remaining in communication with NRL throughout the entire trip.
- A NRL HF crystal-controlled transmitter communicated directly with the flagship, USS *Seattle*, during the cruise of the Fleet to Australia in 1925.
- NRL maintained regular communications with the Antarctic base and support ships of Commander R.E. Byrd's expedition to the South Pole in 1929. The base and ships were equipped with radio gear designed and fabricated by NRL.

### Communication Moon Relay

- In 1951, NRL was the first to demonstrate that radio energy reflected from the Moon was much more coherent than predicted. As a consequence, a Moon circuit could be used to transmit data at a rate and fidelity adequate for radio communication. NRL then developed the key transmitter and receiver technologies that allowed effective communication through a passive Moon circuit.
- In 1954, NRL was the first to transmit and return the human voice through outer space.
- In 1955, NRL first demonstrated transcontinental satellite communication, from Washington, DC, to San Diego, California.
- In 1959, the world's first operational satellite communication system, allowing communications from Washington, DC, to Oahu, Hawaii, was placed in operation. The public demonstration of this system took place on January 28, 1960 with the exchange of messages between the Chief of Naval Operations and the Commander-in-Chief, Pacific Fleet.



### Subscriber Terminal Unit, Third Generation (STU-III)

- NRL provided voice processing algorithms for the STU-III, which is a secure voice terminal widely deployed to support narrowband tactical and office-to-office voice communications developed by NSA.





# SYSTEMS

## NAVY RADAR

### Development of the Radar Principle and Invention of the First U.S. Radar



Prior to the development of radar, Navy ships could track other ships or aircraft only by using optical techniques, sound ranging, or primitive radio direction finding. New methods of detection and ranging were necessary. In the autumn of 1922, NRL had made the first detection of a moving ship by radio waves and had, as a result, discovered the radar principle. Eight years after the initial discovery of the radar principle, NRL scientists noted that the reflections of radio waves from an airplane could also be detected.

From 1930 to 1940, NRL explored the use of radio for detection and ranging, and in 1935 the Committee on Naval Appropriations of the U.S. House of Representatives allocated \$100,000 to NRL for the development of radar. This led to NRL's invention and development of the first U.S. radar, the XAF (installed on the battleship USS *New York* in 1939), and led eventually to its commercial production form, the CXAM. By the time of Japan's attack on Pearl Harbor, 20 radar units were in operation on selected vessels. These radars contributed to the victories of the U.S. Navy in the battles of the Coral Sea, Midway, and Guadalcanal.

### Naval Radar Systems

Following the discovery of the radar principle and the invention and development of the first U.S. radar, NRL established a tradition of excellence in radar research and development that led to other important technological advances. Such achievements in the development of radar systems include:

#### Duplexer

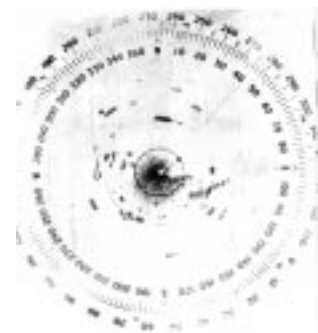
The use of a pulse technique to detect aircraft and ships was proposed by NRL's Leo Young in 1933. His colleague, Robert M. Page, made important advances over the next few years in the area of transmitters and receivers. He eventually developed the highly important duplexer, which permitted an antenna to be used for both transmitting and receiving. Combined with the duplexer, the pulse technique did away with the separate receiving and transmitting antennas that early radar developers had used.

#### Submarine Radar

In 1940, NRL developed submarine radar. This radar enabled a submarine to rise to periscope depth and search for hostile aircraft before surfacing. Aircraft could be detected by the radar out to a range of 20 miles. At that time, this was considered adequate to allow the submarine to submerge before becoming vulnerable to the aircraft's weapons. This radar became popular with submarine skippers during World War II; units were installed in submarines as quickly as they became available—more than 400 were produced. The Laboratory later perfected a directional radar antenna for use with the Western Electric Radar System. It was effective enough to be used as a fire-control instrument, allowing several enemy ships to be torpedoed without the submarine being seen.

#### Plan-Position Indicator

To provide a polar-coordinate map-like display of targets, NRL originated the radar plan-position indicator (PPI)—the well known radar scope with the round face and the sweeping hand—between 1939 and 1940. The PPI is now universally used by military and commercial interests around the world for the display of radar information for such functions as air and surface detection, navigation, air traffic control, air intercept, and object identification.



# SYSTEMS

## NAVY RADAR



### Monopulse Radar

In 1943, NRL developed monopulse radar, now the basis for all modern tracking and missile control radars. The monopulse technique was first applied to the Nike-Ajax missile system, which at the time was the nation's continental air defense system. Monopulse radar eventually led to the development of the AN/FPS-16, the first high-precision monopulse instrumentation radar. In 1958, this radar was used to guide the launchings of the first U.S. space satellites at Cape Canaveral. Monopulse radar is still the most widely used technique for military tracking radar because of its high accuracy and relative immunity to electronic countermeasures that degrade other tracking methods.

### Airborne Radar

Prior to America's entry into World War II and in anticipation of the German submarine menace, NRL developed the Model ASB radar. It was the first operational U.S. airborne radar to be widely used for bombing, detection of ships and surfaced submarines, and airborne intercept. This radar saw extensive use during the war, not just by the U.S. Navy and Army Air Forces, but also by the British. It was installed almost universally in U.S. naval aircraft and became known as the "Workhorse of Naval Aviation." The Model ASB was the first radar to be used in carrier-based aircraft and was used in attacking and destroying Japanese ship convoys in the Pacific. It was also effective against Japanese aircraft. It has been said that the ASB "was one of the most successful of all airborne surface search radars."



### Over-the-Horizon Radar

During the late 1940s, NRL foresaw the need to detect moving targets, including aircraft and missiles, at distances and altitudes beyond the line-of-sight. NRL began to investigate the use of radar operating in the high frequency (HF, or short wave) portion of the radio spectrum to extend the range beyond the horizon. By 1955, NRL was operating a low-power HF radar system called Multiple Storage, Integration, and Correlation (MUSIC). By using signals reflected by the ionosphere as well as by the target, MUSIC allowed the detection of missile launches at distances up to 600 nautical miles and of atomic explosions at distances up to 1700 nautical miles. A much improved system called Magnetic-Drum Radar Equipment (MADRE) was developed in 1961 and was installed at NRL's Chesapeake Bay Detachment.





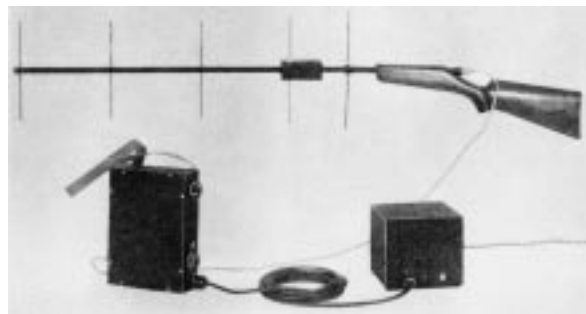
# SYSTEMS

## NAVY RADAR

### Identification Friend-or-Foe

In the 1930s, neither the Army nor the Navy had a device that could adequately identify targets on the ground, sea, or in the air. Identifying friendly planes returning to carriers under poor visibility was an especially serious problem. To solve the problem, NRL sought solutions through the use of radio waves.

- In 1937, NRL developed the first U.S. radio recognition identification friend-or-foe (IFF) system, the Model XAE, which met an urgent operational requirement to allow discrimination of friendly units from enemy units.
- The Mark X IFF was a later radar beacon system developed by NRL. It was essential to the military because it reduced fratricide when used with beyond-visual-range weapons.
- By 1958, the FAA had established the Air Traffic Control Radar Beacon System (ATCRBS), which is essentially the civil version of the Mark X. The International Civil Air Organization later adopted the ATCRBS, making the Mark X the basis of the world's air traffic control system.
- In 1960, the Mark XII IFF system was developed. It was the first IFF system to use cryptographic techniques to prevent deception where an enemy appears as a friend by using a captured transponder.



## ROCKET PROGRAMS

### V-2 Rockets

After World War II, parts of almost 100 German V-2 rockets were brought to the United States. The U.S. Army undertook the task of assembling the rockets at White Sands, New Mexico, for research and experimentation by government agencies and universities. In 1946, NRL was invited to participate in the Army's V-2 rocket program. As an established group ready to carry out upper atmospheric research, the Laboratory became the prime agency for conducting research with the V-2 program and for developing the technology to carry out the missions. Eighty experiments were performed during the program, which lasted from 1946 to 1951. As a result, new and valuable information was gained about the nature of the Earth's upper atmosphere and ionosphere.

NRL's major V-2 program accomplishments include:

- the first direct measurement of atmospheric pressure above 30 kilometers (18 miles);
- the first photos of Earth from 64-, 112-, and 162-kilometers (40-, 70- and 101 miles) altitude;
- the first photos of the ultraviolet solar spectrum below 285 angstroms;
- the first detection of solar Lyman-alpha radiation;
- the first detection and measurement of solar X rays; and
- the first direct measurement of the profile of ionospheric electron density versus height.



This was the birth of both space-based astronomy and the U.S. Navy's space program. When it became evident that the supply of V-2 rockets would be exhausted, NRL proceeded to develop its own rocket.

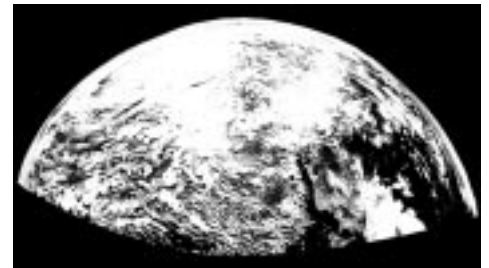
# ROCKET PROGRAMS



## Viking Program

In 1946, NRL directed the development of a new sounding rocket called Viking, which was designed and built by the Glenn L. Martin Company. Viking embodied the successful, important innovations of a gimballed motor for steering and intermittent gas jets for stabilizing the vehicle after the main power cutoff. These devices are now extensively used in large, steerable rockets and in space vehicles. The engine was one of the first three large, liquid-propelled, rocket-powered engines produced in the United States. A total of twelve Viking rockets were launched from 1949 to 1954. The first attained a 50-mile altitude and Viking-11 rose to 158 miles, an all-time altitude record for a single-stage rocket. Through these Viking firings, NRL was first to measure temperature, pressure, and winds in the upper atmosphere and electron density in the ionosphere, and to record the ultraviolet spectra of the Sun. NRL also took the first high-altitude pictures of the Earth.

On October 5, 1954, during a launching over New Mexico, a camera mounted in an NRL Viking rocket took the first picture of a hurricane and a tropical storm, from altitudes as high as 100 miles. The picture embraced an area more than 1000 miles in diameter, including Mexico and the area from Texas to Iowa. This was also the first natural-color picture of Earth from rocket altitudes. The success NRL achieved in this series of experiments encouraged Laboratory scientists to believe that, with a more powerful engine and the addition of upper stages, the Viking rocket could be made a vehicle capable of launching an Earth satellite. This led to NRL's Vanguard project.



## Aerobee

NRL participated in the development of several rockets, the earliest of which was the Aerobee. These relatively inexpensive rockets were used for 31 upper atmosphere experiments specially suited to their capability. Later redesigned into the Aerobee-Hi with an enlarged fuel tank, it was used for three flights in 1957 in conjunction with the International Geophysical Year.

## Rockoon

In the 1950s, NRL used a balloon-rocket combination (Rockoon) in experiments to investigate solar radiation and cosmic rays. The plastic balloon lifted the Deacon rocket to 21 kilometers (70,000 feet) where it was fired by a pressure-sensing device. By this technique, the rocket could carry a 22-kilogram (50-pound) payload to an altitude of more than 130 kilometers (80 miles).



# ROCKET PROGRAMS

## Nike Booster

NRL devised systems using Nike Boosters with several different second-stage rockets. These vehicles were used primarily to study the sun during the International Geophysical Year (July 1957 - December 1958).



## Vanguard Project

Between 1955 and 1959, NRL conducted the first American satellite program called Vanguard. The program was initiated to represent the United States in the International Geophysical Year (IGY). IGY was a cooperative international scientific effort to study the physical properties of Earth. The nation's leaders in science decided to participate in the IGY by placing an artificial satellite in orbit. Following this decision, a competition was held to determine which U.S. government agency would build and launch the satellite. The plan submitted by NRL was selected due, in part, to its success with the Viking Program. NRL's pioneering task was to design, build, launch, place in Earth orbit, and track an artificial satellite carrying a scientific experiment.

In 1957, because suitable satellite-launching facilities were not available, NRL constructed the first complete satellite-launching facility at Cape Canaveral, Florida. Central control of this facility was maintained at the main NRL site in Washington, D.C. Critical functions involved in attaining orbit had to be performed many hundreds of miles from the launch pad. NRL had developed in 1956 the first satellite-tracking system, called Mini track, which provided the first down-range instrumentation for determining the orbit of a satellite. This system evolved from NRL's work on phase comparison and angle tracking and used a series of fan-shaped, vertical antenna beams.

The Vanguard I satellite was successfully launched into Earth orbit on March 17, 1958. Vanguard I achieved the highest altitude of any man-made vehicle to that time and established beyond doubt geologists' suspicions that Earth is pear shaped. It carried two radios and a temperature sensor and was the first orbiting vehicle to be powered by solar energy. Photovoltaic silicon solar cells provided the electrical power to the 6.4-inch, 3.5-pound satellite until its experiments and transmitter fell silent in 1964. Vanguard I orbits Earth today as the oldest man-made satellite and will remain in orbit well into the 22nd century.



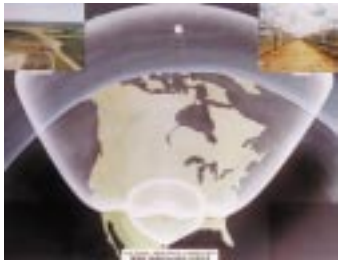
Vanguard II, launched on February 17, 1959, was the first satellite designed to observe and record the cloud cover of the Earth and was a forerunner of the television infrared observation satellites (TIROS). It was also the first full-scale Vanguard (20-inch diameter sphere, 21 pounds) to be launched. Both Vanguard I and II are still in orbit. The scientific experiments flown on the Vanguard satellites increased scientific knowledge of space and opened the way for more sophisticated experiments. Vanguard was the prototype for much of what became the U.S. space program.

When the National Aeronautics and Space Administration (NASA) was established on July 29, 1958, the NRL Vanguard group, a total of approximately 200 scientists and engineers, became the core of its spaceflight activities. The group remained housed at NRL until the new facilities at the Goddard Space Flight Center at Beltsville, Maryland, became available in September 1960.

# ROCKET PROGRAMS

## NavSpaSur

After the Soviet launch of Sputnik I in 1957, detecting and tracking foreign satellites orbiting over the U.S. became a major national security issue. As a result, the Navy Space Surveillance System (NavSpaSur) was developed (1958-1964) by NRL on a “crash basis” for the Advanced Research Projects Agency to detect and track such satellites. NRL was selected to



develop this system primarily because of its success in developing the Minitrack satellite tracking network for project Vanguard. Unlike the Vanguard tracking system, NavSpaSur was designed to track both satellites that transmitted signals and those that were “quiet.” NavSpaSur now consists of nine radar sites stretching between southern California and Georgia and comprises a radar “fence” capable of detecting basketball-sized objects in orbit as high as 7,500 miles above Earth. The information gathered by this system is used to maintain and update the catalogs of orbiting objects, detect newly orbited objects, and warn U.S. military units of periods when they would be vulnerable to detection by foreign satellites.

## SOLAR AND LUNAR STUDIES

### SOLRAD/GRAB

The SOLar RADiation satellite program (SOLRAD) was conceived in the late 1950s as an improved means of studying the sun’s effects on Earth, particularly during periods of heightened solar activity. Of prime interest were the effects of solar radiation on the ionosphere, which had critical importance to Naval communications. SOLRAD was NRL’s and the nation’s longest continuing series of satellite projects dedicated to a specific research program. SOLRAD I was launched in June 1960, and ten more SOLRADs were fabricated by NRL and flown through 1976.

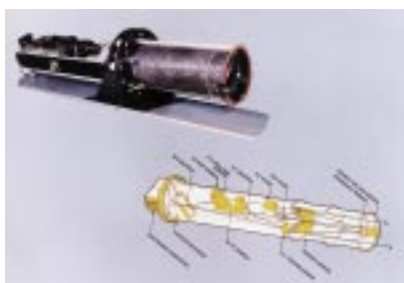


SOLRAD I was unique in that it:

- determined that radio fade-outs were caused by solar X-ray emissions;
- was one of the two satellites launched during the world’s first multiple satellite launching;
- was the world’s first orbiting astronomical observatory; and
- was the first satellite to be successfully commanded to shut off.

NRL’s SOLRAD series of satellites yielded important new scientific information on the sun’s effects on Earth’s atmosphere. The new knowledge gained by the program also yielded practical, and in some cases critical, benefits to Naval communication and the U.S. manned space program.

The Galactic Radiation and Background I (GRAB I) payload, a recently declassified co-flyer with SOLRAD I, was America’s first operational intelligence satellite. In June 1960, fifty-two days after a U-2 aircraft was lost on a reconnaissance mission over Soviet territory, the GRAB I satellite soared into orbit and began transponding space-intercepted electronic intelligence signals to Earthbound signals intelligence stations. The GRAB project provided proof-of-concept for satellite-collected electronic intelligence. This was accomplished by demonstrating that a platform in outer space could collect as much as all other sea-, air-, and land-based reconnaissance platforms operating within the satellite’s field of view at a fraction of their cost and at no risk to personnel.



### HRTS

NRL’s High Resolution Telescope and Spectrograph (HRTS) is a high-powered telescope that sees in the ultraviolet and has the ability to zoom in on very small features on the surface of the Sun.

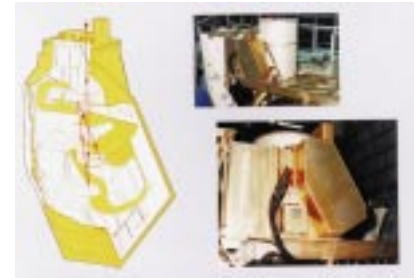
Since its first flight in 1975, the HRTS has recorded high-quality ultraviolet spectra of the Sun on 10 rocket flights and during extended operations on the Space Shuttle Spacelab 2 mission in 1985.



# SOLAR AND LUNAR STUDIES

## SUSIM

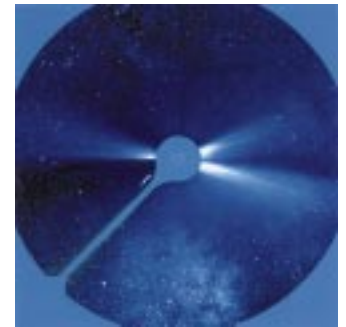
NASA sponsors two Solar Ultraviolet Spectral Irradiance Monitor (SUSIM) instruments in the SUSIM program at the Naval Research Laboratory. Each measures the absolute irradiance of the solar ultraviolet (UV) light in the 115- to 410-nm wavelength range. The SUSIMATLAS instrument has flown repeatedly on the Space Shuttle. The SUSIM UARS instrument has taken data aboard the Upper Atmosphere Research Satellite (UARS) since October 1991.



## LASCO

The Large Angle Spectrometric Coronagraph (LASCO) was developed for flight in 1995 on the Solar and Heliospheric Observatory (SOHO). LASCO is a wide-field white light and spectrometric coronagraph. It consists of three optical systems with nested fields of view that together observe the solar corona from 1.1 to 32 solar radii. One solar radius is about 700,000 kilometers, 420,000 miles or 16 arc minutes. A coronagraph is a telescope that is designed to block light coming from the solar disk in order to see the extremely faint emission from the region around the sun, called the corona.

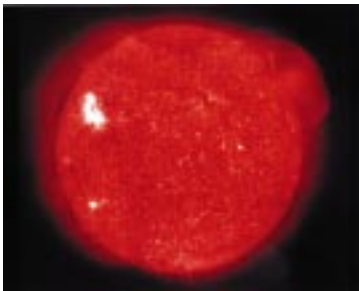
On December 23, 1996, the LASCO experiment on the SOHO satellite recorded images of a large “coronal mass ejection.” The bright ring in the center of the image represents the diameter of the visible Sun. The dark circle surrounding it is an image of the occulting disk, which blocks the glaring light of the Sun from the entrance lens of the telescope. A comet is shown on the lower left of the image. Its path curves toward the Sun, and on December 23 it disappears behind the occulting mask of the coronagraph.



Coronal mass ejections are the hurricanes of space weather. SOHO is ideally placed and instrumented to report and even anticipate their origins in the Sun’s atmosphere. Although the Sun is supposedly very quiet at present, being close to the minimum count of sunspots, LASCO observes so many outbursts large and small—roughly one a day—that scientists are having to think again about how to define a coronal mass ejection.

## EIT

The Extreme Ultraviolet Imaging Telescope (EIT) is a small but powerful telescope aboard the SOHO spacecraft that has been operational since January 2, 1996. EIT uses specially coated, normal incidence reflective optics and filters to image the Sun and its unimaginably hot outer atmosphere with high precision and cadence.



The EIT telescope was designed and built by an international consortium of scientists associated with many institutes. The Naval Research Laboratory developed the CCD camera and the entire electronic support package. Using EIT as a keystone for many other experiments onboard SOHO, scientists are striving to understand the nature of the mechanisms that heat the corona to temperatures far higher than the Sun’s surface gases, and that drive the solar wind outward at speeds of more than a million miles per hour. The solar atmosphere is layered, like the skins of an onion, with the layers marked by higher and higher temperatures as one looks at higher and higher altitudes in the solar “sky” of searing heat and blinding light. Unlike an onion though, the Sun’s surface (or photosphere,

at about 6,000 degrees Celsius) and the atmospheric layers above it (the chromosphere and corona) are by no means smooth and symmetrical. On the contrary, they are pierced through and through with a lacy forest of magnetic fields that rise in giant plumes and arches, surging in constant motion, waxing and waning, and sometimes thrashing like whips or erupting with explosive violence.

EIT has four optical “channels,” each providing images of the Sun in a different temperature regime, and therefore a different “layer” of the Sun’s outer atmosphere.



# SOLAR AND LUNAR STUDIES

## EIT (continued)

Seen here is the chromosphere, a layer just above the white photospheric disk visible to our eyes. Its temperatures range from about 20,000 to 100,000 degrees Celsius, making it too hot to be seen in visible light. It is imaged here in the ultraviolet emission of singly ionized helium, at a wavelength of 304 Å. The large arch surging above the limb at upper right is a prominence, or condensation of this “cool” helium (compared to the million-degree corona surrounding it!) held up against gravity by magnetic forces. This frame shows the prominence in the process of erupting, subsequently to be thrown into outer space, where it will eventually become part of the interplanetary solar wind.

## Clementine

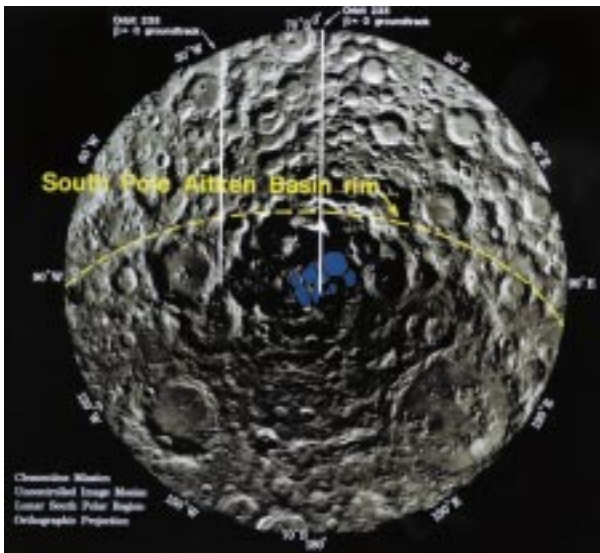
On January 25, 1994, the Deep Space Program Science Experiment (better known as *Clementine*) was launched from Vandenberg Air Force Base, California, on a mission designed to test lightweight miniature sensors and advanced spacecraft components by exposing them, over a long period of time, to the difficult environment of outer space. In addition to testing the various sensors, *Clementine* was given the complex task of mapping the Moon. The mission results were spectacular.

By implementing the “faster, cheaper, better” management approach, *Clementine* was able to move from conceptual design to launch in only 22 months and at a cost of 80 million dollars (including the launch and mapping operations). This was the first time this particular approach was used in a space program. The costs of previous deep space missions had been significantly higher and took a great deal more time to develop.

Between February 26 and April 22, *Clementine* was able to deliver more than 1.8 million digital images of the Moon back to the *Clementine* ground network, including the NRL satellite ground-tracking station located in Pomonkey, Maryland. These images were quickly accessible to the general public via the Internet and World Wide Web. When scientists reviewed the data from *Clementine*, they made a major scientific discovery: the possible existence of ice within some of the Moon’s craters. This discovery was confirmed in early 1998 by NASA’s Lunar Prospector.



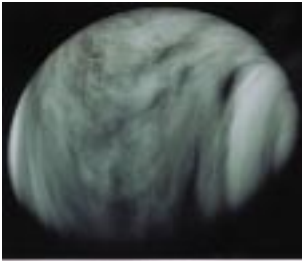
In 1994, President Clinton cited *Clementine* as one of the major national achievements in aeronautics in space. He stated “The relatively inexpensive, rapidly built spacecraft constituted a major revolution in spacecraft management and design; it also contributed significantly to lunar studies by photographing 1.8 million images of the surface of the Moon.” The President was not alone in his praise of *Clementine*. In addition to the President’s comments, *Clementine* and the people associated with the program were presented with the following awards:



- *Popular Science* magazine: Best of 1994’s Top 100 Technologies
- *Aviation Week and Space Technology*: 1994 Laureate Award
- National Space Club: Nelson P. Jackson Award
- Rotary National Award for Space Achievement
- Navy Award for Group Achievement
- *Discover* magazine: 1994 Award for Outstanding Technological Innovation
- 1996 Induction into the Space Hall of Fame

# THE ASTRONOMY REVOLUTION

Through its work in space research and space systems development, NRL has played a major role in establishing space science as a new field of scientific inquiry. NRL pioneered in the development and use of new techniques and technologies for conducting ground-based astronomical research and for exploiting the potential of spaceflight for the performance of astronomical and geophysical research in the upper atmosphere and space. In the late 1940s and the 1950s NRL was a major international center for space-science research, and in the 1960s and 1970s the Laboratory provided much of the expertise for the space-science programs carried out by NASA and others.



## Radio Astronomy

Radio astronomy came into being in the late 1940s when astronomers realized that radio waves from outer space could be used, as light waves were used, to measure the physical characteristics of objects in space and their relative distances from the Earth. Radio astronomy has been concerned with the study of the strength, direction, and variation in radio emissions from the Sun, Moon, and stars. The principal tool has been the radio telescope, which uses a large, concave metal reflector and a directive radio-receiving antenna. In 1951, NRL produced the

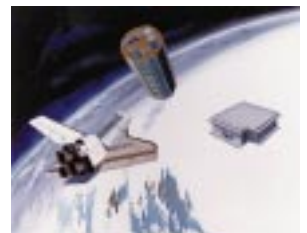
largest accurately figured radio telescope, a 15-meter (50-foot), machined-aluminum, steerable paraboloid installed atop NRL's Building 43. Accomplishments by NRL using this telescope included:

- the first detection and measurement of interstellar ionized atomic hydrogen clouds as discrete radio sources (1953);
- the first detection of the absorption of emission of radio stars by interstellar hydrogen gas (1956);
- the first detection of radio emissions from Mars, Venus, Jupiter, and Saturn (1956 to 1958);
- the first successful measurement of surface temperatures of Venus, Mars, and Jupiter; and
- the first measurement of the spectrum of continuous radio emission from the Crab Nebula.

## Cosmic-ray Physics

Studies of cosmic rays by NRL began in 1949. For the next ten years NRL physicists developed detectors for identifying relativistic particles in cosmic rays. The detectors consisted of stacks of sensitive emulsions, and after a particle passed through, the path could be traced and analyzed. In the 1960s and 1970s, the NRL cosmic-ray-physics program shifted from particle studies to the stars, the origin of these cosmic rays. During the Gemini XI mission, NRL had several detector trays on the spacecraft that yielded important information on the origin and history of cosmic rays. NRL's principal vehicle for studying cosmic rays, however, was the Skyhook balloon, a 283,000-cubic-meter (10-million-cubic-foot) plastic balloon that carried detectors to an altitude of 43 kilometers (140,000 feet).

From April 7, 1984 to January 12, 1990, NRL's Heavy Ions in Space (HIIS) experiment flew aboard NASA's Long Duration Exposure Facility (LDEF). The HIIS detectors were mounted on the space-facing end of the LDEF and comprised large stacks of plastic track detectors with a total geometry factor of 2.0 m<sup>2</sup>-sr. HIIS is one of the largest cosmic ray experiments ever flown.



The following are some of the scientific results from HIIS:

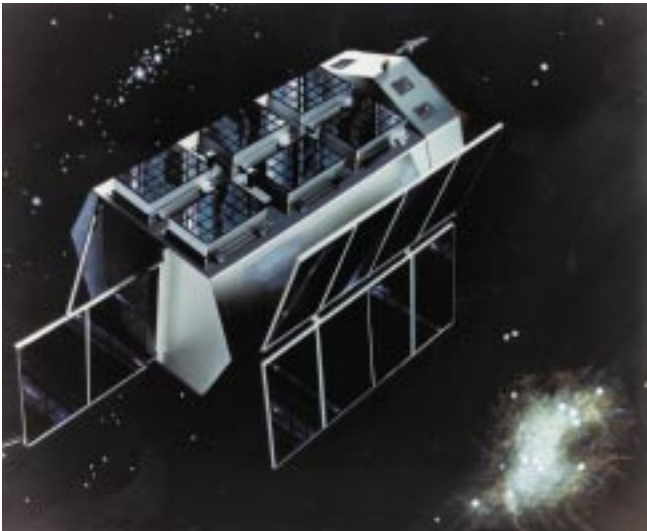
- The HIIS experiment has provided the first measurements of the ionic charge state of solar energetic Fe ions at very high energies.
- HIIS, in conjunction with other cosmic ray detectors aboard LDEF, has provided new observations of trapped anomalous cosmic rays. In addition, the LDEF experiments have provided evidence of additional species (Mg, Si, and Fe) whose origin is not yet understood.
- HIIS collected a sample of "ultraheavy" galactic cosmic rays (UHGCRs) roughly three times larger than accumulated in previous experiments. Analysis of the HIIS UHGCRs is still in progress.

# THE ASTRONOMY REVOLUTION

## X-ray Astronomy

In 1963, NRL astronomers made the first positive identification of discrete sources of stellar X rays. A new NRL-developed X-ray detector system was flown on an Aerobee rocket, and the result was the discovery of two X-ray sources - Scorpius X-1 and the Crab Nebula. These findings suggested the possibility that the source of the X rays was a neutron star, a densely packed body of neutrons formed from the collapse of a star. NRL scientists wanted to prove this hypothesis, and in 1964 NRL conducted an experiment on an Aerobee flight during the occultation of the Crab Nebula by the Moon. NRL's data did not confirm the neutron-star theory, which in turn spurred more intensive investigations. As a result, between 1964 and 1973, 125 discrete sources were discovered, including supernova remnants, pulsars, radio galaxies, and quasars. Specific NRL contributions included:

- the first X-ray detection of a pulsar in the Crab Nebula in 1969;
- the detection of X-ray galaxies during Aerobee flights in 1967 and 1968;
- the compilation of the first comprehensive galactic X-ray sources map;
- the discovery of a distinctive difference in time behavior between soft and hard X rays in 1971; and
- the discovery of the variability of Cygnus X-1, a possible black hole in the Cygnus constellation.



The rapid development of X-ray astronomy, combined with developments in infrared, ultraviolet, and cosmic-ray investigations, led in the 1970s to the utilization of satellites for high-energy astronomy research. In 1972, NASA initiated the High Energy Astronomy Observatory (HEAO) program to study cosmic-ray, X-ray, and gamma-ray sources in deep space. NRL was selected to develop one of the four instrument packages to be flown on the HEAO I, which was launched in August 1977. The NRL package, the Large Area X-Ray Survey Array, was the largest space instrument ever to be flown on any satellite. Consisting of seven modules of large-area proportional counters, the instrument mapped the entire sky for high-energy sources, which included radio pulsars, binary pulsars, black holes, quasars, and extragalactic X-ray sources, resulting in a new map of nearly 1000 discrete X-ray sources.



# THE ASTRONOMY REVOLUTION

## OSSE

The Oriented Scintillation Spectrometer Experiment (OSSE) was launched on NASA's COMPTON Gamma Ray Observatory (CGRO) in April 1991. This 35,000-pound satellite is the most advanced mission to undertake scientific observations in high-energy astrophysics. The observatory provides continuous coverage of the most energetic phenomena in nature and can respond to targets of opportunity such as new supernovae or major solar flare activity. The mission has continued to provide high-quality data since its launch.

OSSE has been monitoring a new galactic X-ray source that erupted without warning in December 1996. The X rays from this object shows half-second pulsations and display irregular outbursts. Pulsations and bursting behavior have been associated with different types of X-ray sources but have never before been seen from the same object. The X rays are probably produced when a neutron star pulls matter off its binary companion star, but there are still many mysteries about this source.



If this object is actually near the Galactic Center, as the OSSE observations suggest, then the power released by this source in X rays exceeds the total energy output of our Sun by a factor of nearly a million, with the bursts being even higher. At these luminosities, most astronomers think that the accreting matter would be blown away by the force of the radiation such that the steady power supply of in-falling matter would be shut off.

Besides bursting, the CGRO observations also show that this source pulses with a 0.467-second period and is in a binary system with an orbital period of 11.76 days. OSSE has now observed this object on three occasions: December 14-20, 1997, January 2-12, and January 16-30, 1998. This is a phenomenon never before seen in X-ray pulsars. It could mean that the location of the X-ray-emitting region moves from one point of the neutron star surface to another when it undergoes an outburst.

OSSE observations also show that the hard X-ray spectra from this source during and between bursts is not significantly different, suggesting that the emission mechanisms for the two intervals are the same. The X rays probably result from the conversion of gravitational energy into radiation when falling matter hits the surface of the neutron star, which is only about 20 km in diameter. This is different from standard X-ray burst sources, which are thought to undergo thermonuclear explosions during outbursts.

New maps of gamma rays from CGRO show evidence of a previously unknown and unexpected cloud of positrons, a form of antimatter, lying some 3,000 light years above the center of our galaxy. NRL researchers expected the maps to show a large cloud of antimatter near the galactic center and along the plane of the Galaxy, produced primarily by the explosions of young massive stars. The maps show this gamma ray activity, but surprisingly they also show a second cloud of antimatter well off the galactic plane.

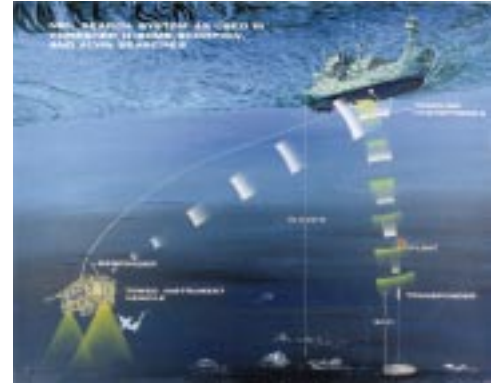
The OSSE instrument, ten times more sensitive than earlier gamma ray experiments, is providing scientists with the first opportunity to undertake comprehensive observations of the distribution and variability of the sources producing the positrons in the Galaxy. To date, OSSE has spent more than a year mapping the distribution of the 511,000-electron-volt gamma rays coming from the center of our Galaxy and searching for variations in the number of gamma rays observed.

# OCEAN AND THE ENVIRONMENT

## Deep-Sea Search

After the tragic loss of the submarine *Thresher* in 1963, the Laboratory designed an unmanned, instrument package that was repeatedly towed over the area where the *Thresher* went down and produced a detailed photomontage showing all known pieces of the wreck. Subsequently, deep-ocean search capability became a major effort at NRL. A Deep Ocean Search System (DOSS) was developed and successfully used in more than 30 search missions between 1965 and 1974, and it located and photographed the lost submarines *Scorpion*, *Alvin*, and *Eurydice*.

In the early 1970s, NRL developed a deep-sea photographic system called LIGHT BEHIND the Camera, or LIBEC. The position of the high-intensity lights in the LIBEC system significantly improved photographic coverage of the ocean bottom.



## Meteorology

Weather forecasting has obvious importance to Naval operations. Accurate weather forecasting depends on an understanding of weather as an atmospheric phenomenon and on increasing knowledge of the atmospheric conditions that affect weather patterns. In the late 1940s, NRL assumed the lead in developing instruments and techniques for making measurements of weather-related atmospheric parameters such as temperature, pressure, and humidity. NRL's axial-flow vortex thermometer made possible the measurement of true air temperature from an aircraft at speeds up to 805 kilometers per hour (500 miles per hour).

NRL undertook an ambitious series of investigations in the late 1940s with the development of instruments and techniques for studying atmospheric conditions and wind patterns using balloons. By 1952, NRL had developed the Transosonde system, a balloon-borne meteorological station for collecting data on temperature, pressure, and humidity over remote or inaccessible ocean areas at a constant elevation of 9 kilometers (30,000 feet). Radio tracking stations followed the balloon's trajectory and mapped out existing air mass systems and their movements. This resulted in an increased understanding of the upper air patterns defining the broader aspects of weather and long-term weather developments. Transosonde was later complemented by Transobuoy, a free-floating weather station instrumented to measure temperature, pressure, wind speed, and direction at and near the ocean surface.

## Improved Forecasts of Damaging Pacific Winter Storms

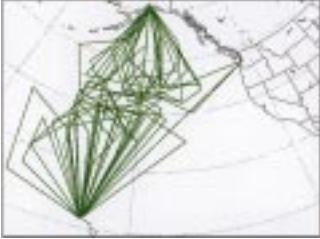
The North Pacific Experiment (NORPEX), conducted jointly by NRL, NOAA, and the USAF during the 1998 winter season, successfully provided the "first line of defense" against El Niño-enhanced winter storms. The mission of NORPEX was to demonstrate that, using sophisticated computer modeling techniques, scientists could identify, in advance, specific areas over the Pacific Ocean where an improved knowledge of atmospheric conditions could lead to improved 1-4 day forecasts of high impact weather over the United States. These identified "areas of sensitivity" were then targeted as regions for taking special observations of atmospheric profiles of temperature, wind, and moisture. These observations were obtained by deploying dropwindsondes from NOAA's new jet, the Gulfstream-IV and from U.S. Air Force C-130 planes from the 53rd Weather Reconnaissance Squadron, temporarily based in Alaska and Hawaii. The additional data obtained along each flight was immediately transmitted back to the National Weather Service and U.S. Navy operational forecast centers in real time for incorporation into their computer forecasting models.





# OCEAN AND THE ENVIRONMENT

January 16 - February 27, 1998

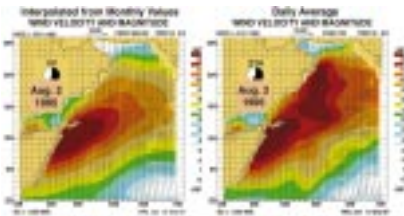


32 Targeted Observing Missions

## Improved Forecasts of Damaging Pacific Winter Storms (continued)

Postexperiment analyses conducted as part of NRL's research on atmospheric predictability indicate that the NORPEX aircraft observations produced major changes in the intensity and track of the jet stream and the major winter storm systems. These changes led to significant improvements in the accuracy of forecasts and warnings for land-falling storms along the U.S. West Coast.

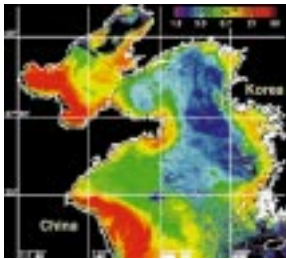
In addition, extended-range forecasts for severe storms in the central and eastern U.S. were also improved by the NORPEX observations up to 4 days in advance. The observations collected in NORPEX represent an unprecedented effort to improve prediction of storms that often develop in areas devoid of most meteorological data. Our capability to pinpoint areas of forecast sensitivity is extremely important for making the most effective use of the relatively few measurements that can be taken over an area as vast as the North Pacific Ocean. These observations of early storm structure are essential for providing the public with improved advance warnings of storm landfall, rain and snow amounts, and flooding potential.



## Monsoon Variability

The Navy's operational atmospheric surface winds in the Arabian Sea were validated through a collaborative project between NRL and ONR-funded scientists at Woods Hole Oceanographic Institute (WHOI). The daily Navy Operational Global Atmospheric Prediction System (NOGAPS) winds from Fleet Numerical Meteorology Oceanography Center (FNMOC) were archived at NRL and used to examine the variability of the

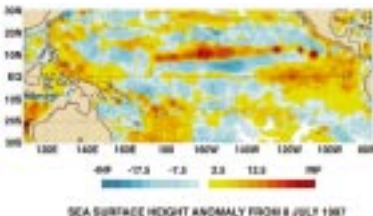
Indian Ocean monsoon surface winds on submonthly time scales. Prior to this study, the monthly averages of ship wind observations provided the state-of-the-art depiction of Indian Ocean surface winds. The figure reveals the rich structure of the daily winds relative to the very smooth monthly averages.



## Mine Countermeasures (MCM) Coastal Optical Program

In 1997, the MCM Coastal Optical Program transitioned the capability for the Naval Oceanographic Office to use AVHRR to determine the coastal optical properties (c660), the beam attenuation coefficient at 660 nm. The new product can be determined from channel 1 and 2 of the AVHRR satellite sensor. An example of the (c660) product is shown for the Korean region, where an image time series is being developed for transition next year. The red colors represent high-(c660) (more turbid) waters. Coastal optics is important for determining when MCM laser imaging

systems can be used operationally. The algorithm and the software was transitioned to the War Fighting Support Center, Naval Oceanographic Office (WSCNAVO) where products are generated. These are the initial steps in providing satellite optical properties for Navy operations.



## Depicting the 1997 El Niño

This figure shows a snapshot (8 July 1997) of model sea surface height anomaly from a 1/4-degree thermodynamic finite-depth model planned for transition to a Navy nowcast/forecast system. Anomalously high sea level is depicted by the red/orange colors, and low sea level by the blues. The model successfully depicts the current El Niño. A classic signature of El Niño is anomalously high sea level in the eastern tropical Pacific, as depicted

by the figure. The anomalously high sea level in the eastern Pacific is the result of an equatorial Kelvin wave that traveled across the basin approximately 2 months before. The Kelvin wave was driven by a relaxation of trade winds.

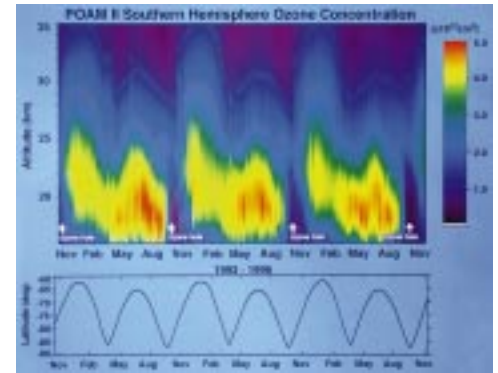
# OCEAN AND THE ENVIRONMENT

## Polar Ozone and Aerosol Measurement

Polar Ozone and Aerosol Measurement (POAM) is a satellite-borne instrument that monitors ozone in the Arctic and Antarctic stratosphere year-round. POAM was developed by NRL to measure the vertical distribution of ozone with a vertical resolution of one kilometer, obtaining 12 measurements each day around a circle of latitude in each hemisphere. The image shows a time series of POAM II measurements of ozone concentration in the lower stratosphere (altitudes between 15 and 35 kilometers). The period begins when POAM II started collecting atmospheric data in mid-October 1993, and ends in November 1996. During this time, POAM II observed all or part of the life cycle of four ozone holes over Antarctica.

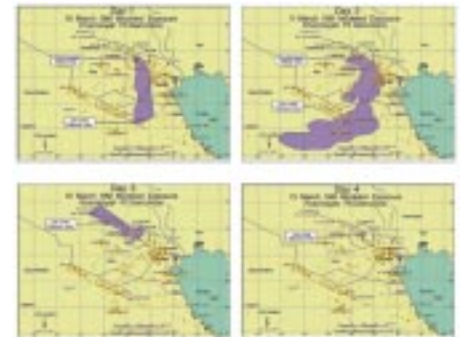
The ozone hole is a severe destruction of ozone in the Antarctic stratosphere that begins in early September and ends in November, during the Antarctic spring. It is apparent from the picture that the destruction extends over a considerable vertical region, from below 15 kilometers to approximately 25 kilometers in altitude.

Conditions for the ozone hole are established early in the Antarctic fall and winter (May through August). During this time, temperatures become low enough to support the growth of Polar Stratospheric Clouds and a wind pattern called the Polar Vortex. The Polar Vortex has been shown to be like a laboratory beaker, containing the polar air and preventing it from mixing with the subpolar air. Chemical reactions on the surface of Polar Stratospheric Cloud particles transform chlorine into a form that can be activated by sunlight. When the Sun rises on the springtime Antarctic stratosphere, its light triggers a complex series of chemical reactions resulting in severe destruction of ozone inside the Polar Vortex. Later in the spring, the concentration of ozone in the polar region increases as the Polar Vortex disintegrates due to rising temperatures and altered winds, allowing undepleted nonpolar air to enter the polar region.



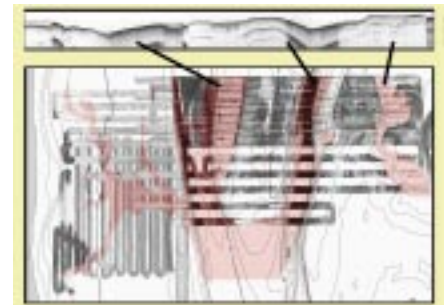
## Meteorological Investigation in Support of the Study for Gulf War Illness

In 1991, a large ammunition storage site near Khamisiyah, Iraq, was destroyed by U.S. Army demolition teams unaware that some of the bunkers contained unmarked chemical rockets. Possible troop exposure to these chemicals was recently explored as part of the Presidential Advisory Committee's investigation into the potential causes of Gulf War Illness (GWI). In support of this investigation, NRL's Marine Meteorology Division in Monterey, California, conducted a forensic meteorological study to estimate where chemicals accidentally released during this demolition may have been transported. NRL provided information about atmospheric conditions such as wind, temperature, moisture, and pressure during and after the demolition.



## Seafloor Mapping and Interpretation

Sidescan sonar imagery and sub-bottom profiler data are commonly used to map and interpret the seafloor. High-frequency (100 and 500 kHz) sound pulses are emitted by the sidescan sonar instrument, which is towed under the sea surface behind a ship. Information on the intensity and travel time of these sound pulses are used to produce black and white photograph-like images of the seafloor. Sub-bottom profiler data are collected from a chirp system that emits a sequence of low-frequency sound waves which penetrate the seafloor. The travel time of the returned signal is recorded and a profile of the geology directly below the seafloor is produced. The sidescan sonar imagery and sub-bottom profiler data, plus other ancillary data such as sediment samples and bottom camera photographs, are used to produce a geological map of the seafloor.



# OCEAN AND THE ENVIRONMENT

## Digital Moving Maps in Aircraft

Since 1990, NRL has supported the Navy's AV-8B and F/A-18 aircraft with map data and design systems. Navy pilots use the map data to drive their cockpit moving-map displays, which are linked to Global Positioning Satellite (GPS) receivers, providing them with hands-off navigation. Naval mission planners use our map design systems to select desired map scales and geographic regions for their flight plans. NRL also developed a system to compress scanned map data by 50:1, considerably reducing the space required to store this data. Now a pilot can access maps covering the entire U.S. (for example) from one optical disk. This is the equivalent of more than 65 4 × 5 in. paper charts.



## MATERIALS FOR A BETTER FUTURE

### Blood Surrogate

NRL has been conducting research on developing techniques for the synthesis of durable, rugged lipids. Lipids are naturally occurring substances that “self-organize” into double layers that make up membranes of living cells. Both naturally occurring and synthetic lipids can be chemically modified. As modified by NRL, these materials have the potential for being applied in new electronic materials, optical elements, acoustic sensors, biological hybrid detection systems, and oxygen and drug delivery to the body.

In 1985, synthetic red cells based on the concept of liposome-encapsulated hemoglobin (LEH) were developed at NRL as a potential blood surrogate. In principle, hemoglobin solutions were added to a mixture of dry phospholipids and cholesterol and the dispersion was extruded under high pressure through narrow channels. The resulting liposomes lacked the blood group antigens, theoretically rendering them “universally” acceptable for transfusions. The blood surrogate was also storable up to 10 times longer than regular blood. Work is underway at NRL to extend the storage lifetime of LEH by freeze-drying; to transfer LEH technology to industry for manufacturing; to establish manufacturing and quality control standards; and to study LEH's physiological effects. The red blood cell surrogate research is directed toward improved methods of combat casualty care. It is hoped that this development may also be used in domestic emergency trauma care as well as in surgical procedures requiring multiple transfusions.



### Permanent Magnet

In 1980, NRL's N.C. Koon and B.N. Das were the first to examine the magnetic properties of rare earth-iron-boron ( $R_2\text{-Fe}_{14}\text{-B}$ ) alloys, which showed promise for permanent magnet use. NRL scientists did the first work on these materials and hold the fundamental U.S. patents. These NRL patents have been licensed to several firms, and products are being offered commercially. Since 1983, commercial alloys based on R-Fe-B have been in commercial production; by 1985, these materials provided almost twice the magnetic energy density of the best materials previously available.

These magnetic materials are eventually expected to cost much less than the older materials because they are made from less expensive and more abundant elements. They also offer relatively good corrosion resistance and are easily formed into complex shapes.

These materials promise to be useful by both the military and commercial sectors for improved microwave tubes, sensors, powerful lightweight electric motors and generators, computer peripherals, and faster, more compact actuators.





# MATERIALS FOR A BETTER FUTURE

## FIRE SUPPRESSION

### Purple-K-Powder

In 1959, a series of original investigations by NRL in the area of chemical flame extinction gave birth to the discovery of a new, dry chemical agent called potassium bicarbonate powder. Powdered bicarbonate of soda as a flame-halting agent had been used for many years, but its action had never been satisfactorily explained. Working with other investigators, NRL conducted fire tests with many powdered substances that helped explain the chemical actions involved. This work came to the conclusion that simple substitution of the potassium ion for sodium extended the flame-quenching efficiencies of the chemical powders by a factor of two. American industry was called in at that point, and the new highly effective product, called Purple-K-Powder by its NRL discoverers, became used throughout the Navy and in U.S. municipal and industrial fire protection operations, and thereafter throughout the world. It is the only dry chemical agent recognized by NFPA for airport crash rescue firefighting.



### Aqueous Film-Forming Foam

Beginning in the early 1960s, NRL conducted research on fire suppression that eventually led to one of the most far-reaching benefits to worldwide aviation safety—the development of aqueous film-forming foam (AFFF). AFFF rapidly extinguishes hydrocarbon fuel fires. It has the additional property of forming an aqueous film on the fuel surface that prevents evaporation and hence, reignition of the fuel once it has been extinguished by the foam. The film also has a unique, self-healing capability whereby scars in the film layer caused by falling debris or firefighting activities are rapidly resealed. This firefighting foam is now used on all U.S. Navy aircraft carriers and by major airports, refineries, and other areas where potentially catastrophic fuel fires can occur. In 1979, this NRL-developed fire suppressant was in use at more than 90 airports in the U.S. alone as well as in many civilian fire departments.

In 1987, AFFF was the primary agent used to prevent a major fire disaster in Fairfax, Virginia. The incident happened on June 11, 1987, when a construction bulldozer ruptured an underground gasoline line. The accident left a gaping hole in the pipeline, spewing thousands of gallons of highly flammable liquid and vapors over a wide area and caused the evacuation of an entire community. AFFF was promptly furnished by fire officials from Dulles International Airport, Bolling and Andrews Air Force Bases, Ft. Belvoir, and the Quantico Marine Corps Base. Officials reported that a total of 4,375 gallons of AFFF and two other types of foam were used at the spill site. In a letter to NRL, the Public Information Officer for the Fairfax County Fire and Rescue Department stated,



“It was clearly a miracle that no ignition source reached the thousands of gallons of gasoline that spewed from the broken pipeline. Had that happened, the entire community of Singleton’s Grove would have been engulfed in flames, and numerous lives undoubtedly would have been lost.”

# MATERIALS FOR A BETTER FUTURE

## THIN ORGANIC FILMS

From 1961 to the early 1980s, NRL conducted basic research on the nature and effects of surface-active organic substances at critical interfaces in the marine environment. This research generated three spin-off applications that used nontoxic, monomolecular aquatic surface films: to control and confine spilled petroleum oils; to function as radar-detectable seamarkers for the search and rescue of personnel and machines lost at sea; and to control mosquito larvae and pupae in their breeding sites.

### Oil Spill Control

NRL discovered that certain surface films applied around oil spilled on water could compress the oil into a much smaller area and maintain the oil in a thick layer, thereby enhancing the efficiency of oil-recovery operations. In 1970, NRL demonstrated the first successful containment of an oil spill at sea by using a monomolecular surface film. On Environmental Protection Day, June 27, 1972, NRL demonstrated the film at the U.S. Naval Academy before high-ranking attendees representing the navies of 33 nations. The keynote speaker for Environmental Protection Day was Jacques Cousteau who, as an advocate of maintaining the cleanliness of the world's oceans, expressed great interest in the NRL oil-control demonstration. Following approval from the Environmental Protection Agency, the method was incorporated into Navy pollution control programs for harbors and bays. It has also been used in commercial training for oil spill control. The oil spill control technique has reduced the damage to property, the fishing industry, and the environment.



### Seamarker Development

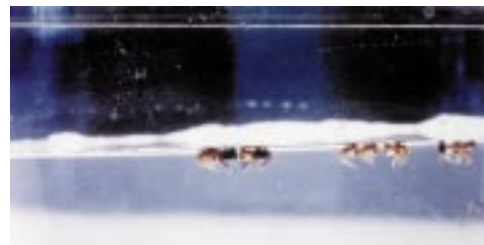
NRL research demonstrated that the one-molecule-thick films on water were readily detectable, both visually and by radar, with radar providing nighttime and poor weather detectability. The films were useful as seamarkers because the films dampen wave action over a wide area of water surface, thereby producing a highly visible artificial sea slick under a variety of environmental conditions. W.D. Garrett and W.R. Barger patented this invention as a chemical sea surface marker in 1972. In developing this product, they made comparative studies with the standard Navy dye marker. When the sea slick and dye were used in combination, the detectability of the resulting marker was greater than

that of either component used alone. This is because the dye-only marker is barely visible at certain angles of viewing where the NRL-developed marker slick is obvious. At certain other angles, where the NRL slick was difficult to see, the dye stripe could easily be observed.

### Mosquito

NRL developed a thin surface film that prevents mosquitos in the pupal and larval stages from attaching to the water's surface where they breathe and feed. This causes them to drown, thus killing by physical, not toxic, means. No pesticide is required nor is a petroleum-based solvent needed to deliver the compound. The method has proven effective against mosquito genera that are carriers of debilitating tropical diseases, including malaria, encephalitis, and dengue fever.

In 1984, the nontoxic mosquito-control substance gained Environmental Protection Agency approval and is currently being manufactured by a chemical company under license from a U.S. Navy patent on this invention. The substance is now commercially available to mosquito control districts across the U.S.





# MATERIALS FOR A BETTER FUTURE

## ATMOSPHERE MONITORING

### Central Atmosphere Monitoring System

In 1975, NRL developed the Central Atmosphere Monitor System (CAMS), which allowed submarine crews, for the first time, to reliably monitor the air aboard their boats. CAMS is a combination carbon dioxide detector and fixed-collector mass spectrometer that monitors hydrogen, water, nitrogen, carbon monoxide, oxygen, carbon dioxide, and refrigerant gases. The system became the first submarine air monitor to be “service approved” and was subsequently installed on all U.S. Navy nuclear submarines. NASA also uses a variant of this system for manned space vehicles.



### Chemical Indicator for Hydrazine

When a space shuttle lands, there is a possibility that there will be residual fuel in its tanks. The fuel, which consists of hydrazine, methylhydrazine, and ammonia, can be highly flammable and explosive when combined with air. Any large fuel leaks must be detected before the crew can disembark or before support personnel and equipment can enter the shuttle landing area. Building on its basic work in analytical chemistry and chemical microsensors, NRL conceived and developed a detector for fuel vapor concentrations in the explosive range that could be used at the space shuttle’s landing site.



## FRACTURE MECHANICS



Fracture mechanics is a field which recognizes that all structures are manufactured with, or will ultimately contain, flaws that govern the eventual failure of the structure. The study of the stresses caused by the flaws and the material’s resistance to failure from them form the basis for the field of fracture mechanics. Fracture mechanics provided, for the first time, the capability to calculate the strength of structures containing defects that inevitably occur in fabrication or during service operation. The net result of these design principles increased the reliability of structures as the result of improved design capability and an improved predictive capability of in-service damage.

NRL’s G.R. Irwin is recognized as the pioneer of modern fracture mechanics. He developed the scientific principles for understanding the relationships between applied stresses and cracks or other defects in metallic materials. Irwin developed, around 1947, the concept that fracture toughness should be measured in terms of resistance to crack propagations. Critical values of the stress intensity describing the onset of fracture, the onset of environmental cracking, and the rate of fatigue crack growth were established later.

Fracture mechanics has been applied throughout the world for the design of any structures where sudden, catastrophic failure would cause loss of life or other serious consequences. Examples include nuclear reactor pressure vessels, submarines, aircraft and missiles, and tanks for storage of toxic or flammable materials.

## HIGH TEMPERATURE SUPERCONDUCTING SPACE EXPERIMENT

The High Temperature Superconductivity Space Experiment (HTSSE-II) is a continuation of a program that began in 1988 when the Department of Defense recognized the military and commercial potential of high temperature superconducting (HTS) materials and devices.

HTSSE was designed to take advantage of the low temperatures that exist in space. HTSSE-I was a self-contained laboratory for testing basic HTS components; HTSSE-II demonstrates the feasibility of advanced HTS devices and subsystems in real-world applications.

As aspiring as the HTSSE program is, it is only the beginning. Based on the results from this program, the Department of Defense and its government and commercial partners are exploring opportunities for using HTS technology in future spacecraft.

Beyond these are commercial applications that only high temperature superconductivity can make possible: dramatically improved cellular and satellite communications systems; tenfold refinements in the accuracy of the Global Positioning System; and aviation radars sensitive enough to detect wind shears.



## DETECTORS/SENSORS

### Microassay On A Card

NRL developed the Microassay on a Card (MAC), which is a portable, handheld, noninstrumental immunoassay that can test for the presence of a wide variety of substances in the environment. The MAC is a simple device to use. A drop of test solution is placed on one side of the card and within minutes a color is developed on the other side in proportion to the amount of substance in the test solution. The MAC is self-contained and self-timed; no reagents or timing are necessary. The MAC can be configured with multiple wells to provide simultaneous testing for multiple species.

MAC's advantages include:

- rapid and sensitive response—completed in under five minutes with nano-gram-per-milliliter sensitivity;
- a visible positive result—a color develops, indicating the presence of a substance;
- designed for field use—the dry chemistry requires only the test solution;
- no instrumentation required;
- results remain permanent for up to one year; and
- no toxic or corrosive reagents are used.

As envisioned, the MAC could be used as an on-site screen for drugs of abuse in urine or saliva. It could also be used for on-the-job drug testing and identifying seized solid materials. Other applications include tests for pregnancy, surveys for environmental contaminants (pesticides), and diagnostics for disease organisms (toxins).



## DETECTORS/SENSORS

### Surface Acoustic Wave Chemical Vapor Sensor

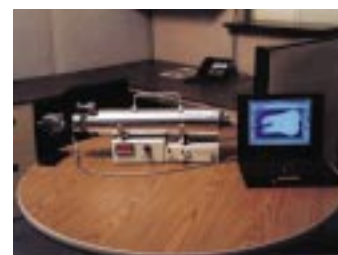
Surface acoustic wave (SAW) sensor systems have been developed as noses for gas detection and identification. System detection limits are in the parts per trillion range. The system operates autonomously with a simple gas sampling system and without the need for support gases. Individual SAW devices operate by generating surface mechanical oscillations in piezoelectric quartz, with frequencies in the MHz range. Coating the SAW devices with different polymeric materials (that selectively absorb different gases) allows gas detection by changes in SAW frequency. Arrays of polymer-coated SAW devices detect different gases, and pattern-recognition techniques interpret data and identify unknown(s). SAW sensor systems are currently being used for monitoring hazardous chemical vapors, chemical warfare agents, potential fires, and environmental pollutants.



### Portable X-ray Unit

NRL has developed an intense pulsed X-ray source for remote imaging of small parts, examination of biological specimens, and calibration and testing of X-ray detectors, X-ray optics and X-ray CCD imaging arrays. Applications of this technology include:

- in situ testing of X-ray detectors and CCD imaging arrays;
- dental X-ray imaging in remote locations;
- in situ examination of injured human extremities;
- complete elimination of motion blurring to allow imaging of small animals without anesthesia; and
- on-site examination of small archeological artifacts when used with a CCD imaging panel and laptop computer.



### Explosive and Contraband Detectors

NRL developed an explosive and contraband detector that uses nuclear quadrupole resonance (NQR) to detect nitrogenous explosives or narcotics carried in luggage, mail, small cargo, or on a person.

Advantages of the NQR system include:

- sensitivity—"threat" quantities of RDX-based explosives can be detected in suitcases;
- specificity—because the NQR resonance frequencies are highly specific to chemical structure, signals from other nitrogenous materials do not interfere;
- throughput—inspection time is approximately 6 seconds for suitcases;
- no magnets are required, therefore, magnetic media are not damaged;
- radio frequency (RF) field strengths are low, minimizing RF exposure to operators and allowing the possibility of examining people;
- minimal operator intervention and interpretation—an alarm is triggered when the NQR signal from an explosive within the interrogated volume exceeds a preset threshold; and
- inherently simple and low cost; unit comprises RF electronics and a PC system.



This NQR approach has been demonstrated for RDX-based explosives in a laboratory setting. The technology can be extended to detect other nitrogenous explosives as well as certain drugs of abuse. As envisioned, such an NQR explosives detector could be useful in airports and other fixed site installations.



## Fiber-Optic Biosensor

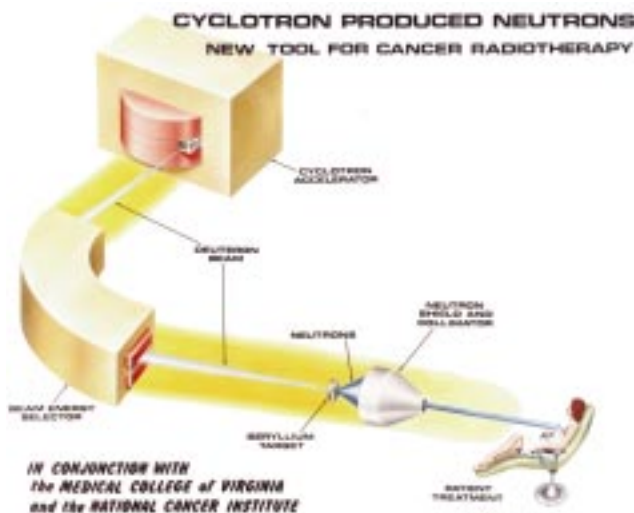
A fiber-optic biosensor has been developed at NRL that uses antibodies, lectins, and antibiotics on the surface of an optical fiber to achieve selectivity. The system is particularly well adapted to detect environmental pollutants and hazardous chemical or biological materials.

The fiber-optic biosensor is a device that measures the formation of a fluorescent complex at the surface of an optical fiber. Antibodies, lectins, and antibiotics provide the mechanism for recognizing an analyte of interest and immobilizing a fluorescent complex on the fiber surface. The biosensor is fast, sensitive, and permits analysis of hazardous materials remote from the instrumentation. A portable sensor has been manufactured and tested on-site for detection of explosives in groundwater. Antibodies coated on the fiber are stable for up to two years of storage prior to use. The biosensor has been developed to detect explosives, pollutants, pathogens, and toxic materials.



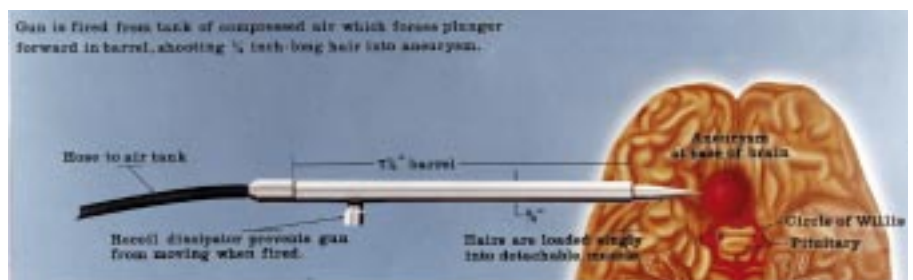
## Cyclotron Particle Accelerator

NRL developed the Cyclotron Particle Accelerator, which produces beams of neutrons, protons, deuterons, and helium and carbon nuclei with energies up to 80 million electron volts. These particles were used for the study of radiation damage to reactor materials, for neutron radiation therapy for cancer, for the production of radioisotopes, and for general radiation research.



## Pilojector

In 1962, NRL developed a surgical technique for correcting intracranial aneurysms to supplant older methods of obliterating these blood-filled arterial dilations. Using a newly developed air gun, called a PILOJECTOR, the surgeon fires one or more short pig bristles into the prominence. Blood around the bristle begins to clot immediately, sharply reducing the size of the aneurysm and strengthening the arterial wall. Only slightly larger than a pencil, the PILOJECTOR offers precise control of position, injection velocity, and penetration.

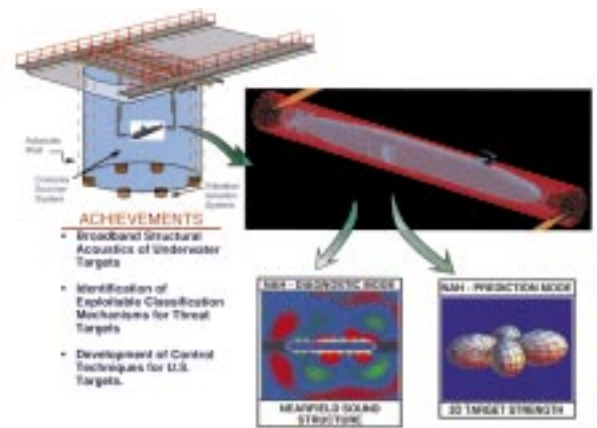


# 75th ANNIVERSARY AWARDS FOR INNOVATION

1. Gamma-Ray Radiography
2. First Operational Fathometer
3. Development of High-Frequency Radio Equipment
4. Radio Propagation and the “Skip-Distance” Effect
5. Invention of U.S. Radar
6. First Operational U.S. Sonar
7. Liquid Thermal Diffusion Process
8. Aircraft Radio Homing System
9. Proposal of a Nuclear Submarine
10. Plan-Position Indicator
11. Identification Friend-or-Foe Systems
12. Monopulse Radar
13. First American Airborne Radar
14. First Far-Ultraviolet Spectrum of the Sun
15. First Detection of X rays from the Sun
16. The Principles of Fracture Mechanics
17. Molecular Structure Analysis and the Nobel Prize
18. The Viking Program
19. Synthetic Lubricants
20. Radar Absorbing Materials and Anechoic Chambers
21. Over-the-Horizon Radar
22. High-Resolution Radar
23. Vanguard Program - The Rocket
24. Vanguard Program - Minitrack and Space Surveillance
25. Vanguard Program - The Satellites and the Science
26. First Operational Satellite Communication System–“Communication Moon Relay”
27. X-Ray Astronomy
28. High-Frequency Direction Finding
29. *SOLRAD I*
30. America’s First Operational Intelligence Satellite
31. High-Power Neodymium Glass Lasers
32. Improved Aircraft Canopy and Window Materials
33. Purple-K-Powder
34. Quantitative X-Ray Fluorescence Analysis
35. Improved Boiler Water Treatment
36. Fracture Test Technology
37. Deep Ocean Search
38. TIMATION and NAVSTAR GPS



Semi-insulating Gallium Arsenide Crystals



Generalized Nearfield Acoustical Holography

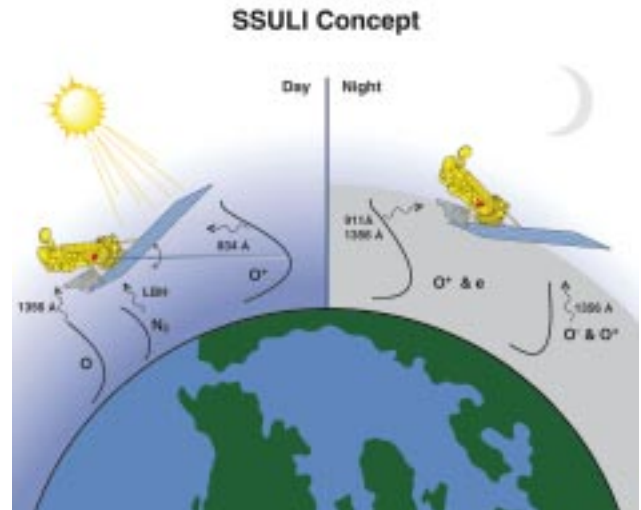


Galactic Radiation Background (GRAB)



# 75th ANNIVERSARY AWARDS FOR INNOVATION

39. Aqueous Film-Forming Foam
40. Radiation Dosimeters
41. Nuclear Reactor Safety
42. Ultraviolet Remote Sensing of the Upper Atmosphere
43. Linear Predictive Coder
44. Submarine Habitability
45. Flux-Corrected Transport
46. High-Power, High-Current Pulsed Power Generators
47. Marine Surface Monolayers
48. Windspeed Measurement Using Microwave Imaging
49. Spaceborne Solar Coronagraphs
50. Fiber-Optic Interferometric Acoustic Sensors
51. Semi-insulating Gallium Arsenide Crystals
52. Super Rapid-Blooming Offboard Chaff
53. Ion Implantation Metallurgy
54. Fluorinated Network Polymers
55. Excimer Laser Technology
56. Specific Emitter Identification
57. Inverse Synthetic Aperture Radar
58. Key Distribution and Management for Cryptographic Equipment
59. Infrared Threat Warning
60. Optical Fiber Gyroscope
61. Permanent Magnet Materials
62. Navy Operational Global Atmospheric Prediction System
63. Generalized Nearfield Acoustical Holography
64. Polar Ice Prediction System
65. Fixed-Wing Airborne Gravimetry
66. Acoustic Matched-Field Processing
67. Magnetic Materials and Semiconductor Technology
68. On-Board Processor
69. Deep Space Program Science Experiment (*Clementine*)
70. Decadal Impact of El Niño
71. Optical Immunoassays and Sensors
72. Dilute Aperture Imaging at Optical Wavelengths
73. Mesoscale Prediction Systems
74. Application of Nuclear Quadrupole Resonance for Detection of Explosives and Narcotics
75. Tactical Receive Equipment



Ultraviolet Remote Sensing of the Upper Atmosphere



Tactical Receive Equipment